PISCES ITER-simulation experiments on Mixed-Materials (Be, C, W)

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R. Doerner, May 9, 2005
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US-EU Collaboration on Mixed-Material PMI Effects for ITER has been extended for 3 years

U.S. - R. Doerner – UCSD   E.U. – A. Loarte - EFDA

Focused on two main experimental aspects:

- The erosion, deuterium retention and codeposition properties of graphite exposed to a beryllium-containing deuterium plasmas

- The erosion, deuterium retention and codeposition properties of tungsten exposed to deuterium plasma containing beryllium impurities (as well as with and without (in TPE) carbon impurities)

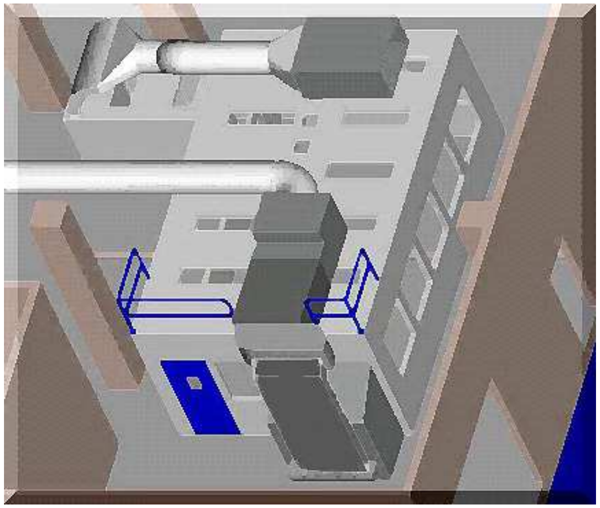
- The erosion and deuterium retention behavior of beryllium exposed to deuterium plasma at temperatures approaching the Be melting temperature

~COMPLETED

Verification of surface and edge plasma models:

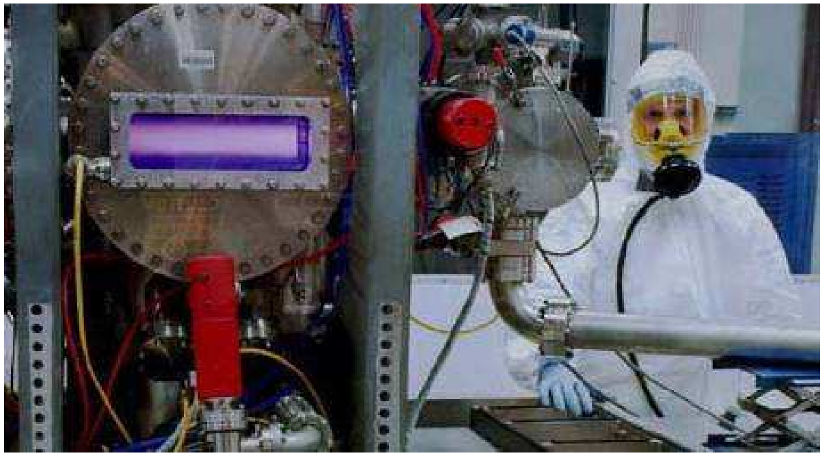
TRIDYN (IPP), ERO (KFA), WBC (ANL), UEDGE (UCSD)

PISCES-B, and Its Associated Surface Analysis Laboratory, Are Compatible with Beryllium Operations.



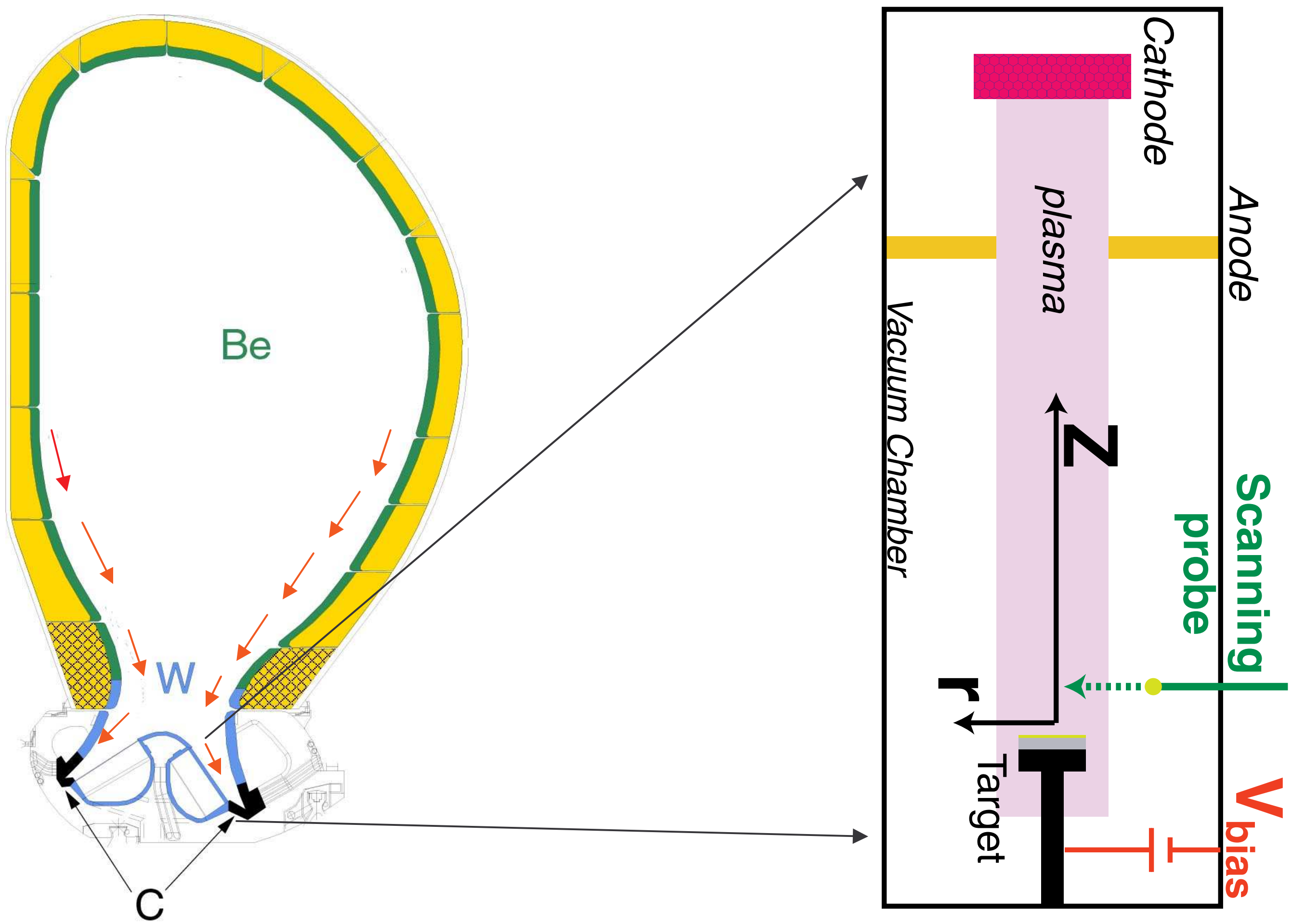
- The PISCES-B plasma generator is contained in a separate enclosure to prevent release of beryllium particulates into the general lab.

- The entire enclosure has a specially designed ventilation system that filters all input and output air streams.

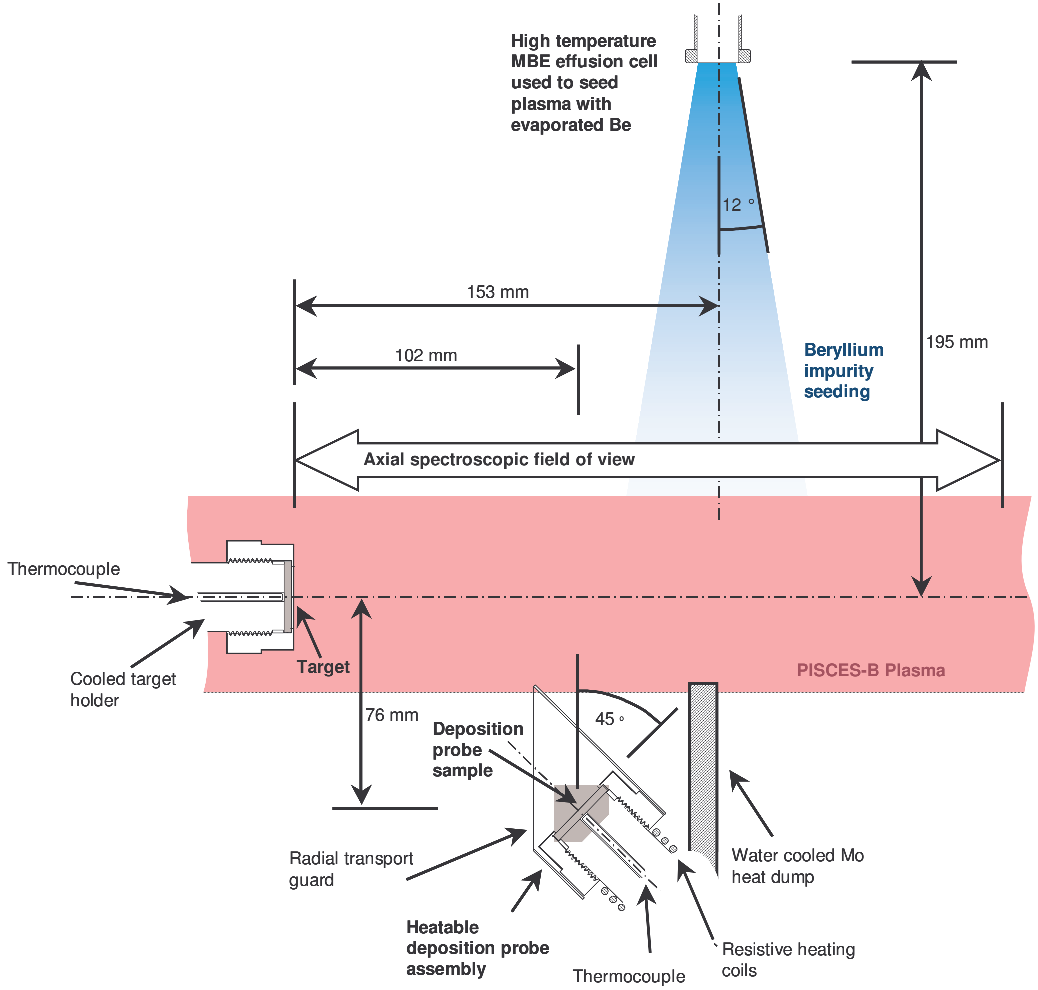


- All personnel entering the enclosure wear full coverage personal protective equipment and follow strict entry and exit procedures when performing routine maintenance, machine repair, or sample handling/exchange operations.

PISCES-B linear plasma device simulates ITER diverted field line geometry

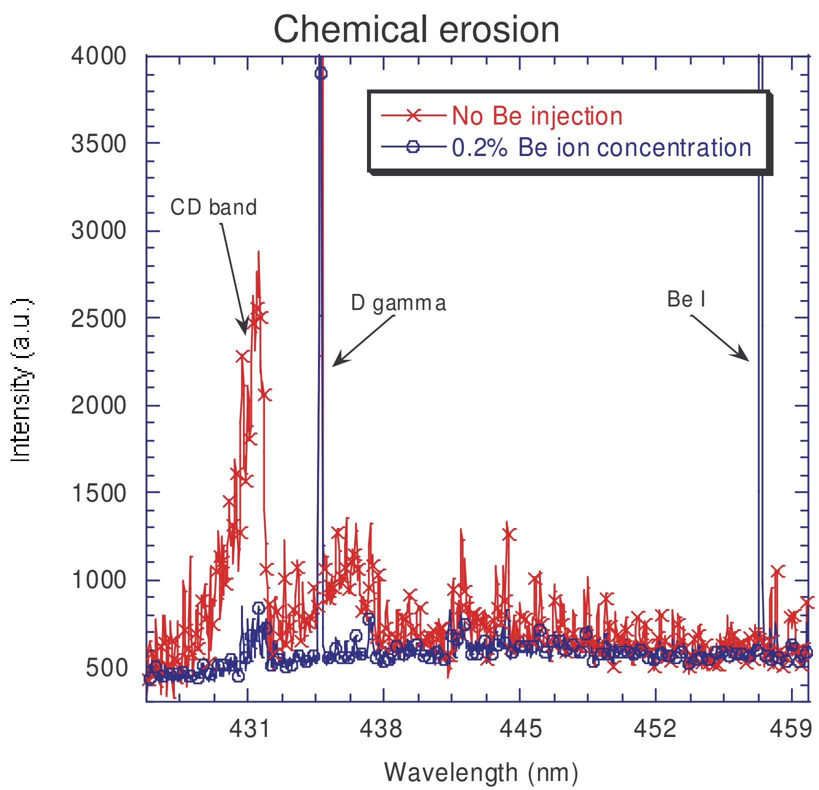


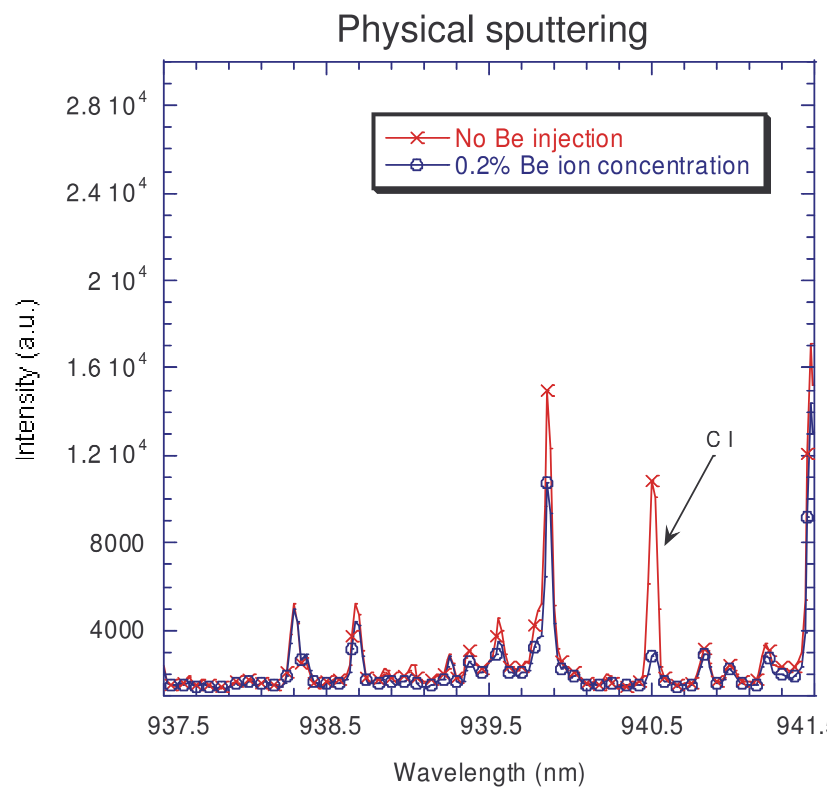
PISCES-B has been modified to allow exposure of samples to Be seeded plasma



A small beryllium impurity concentration in the plasma drastically suppresses carbon erosion

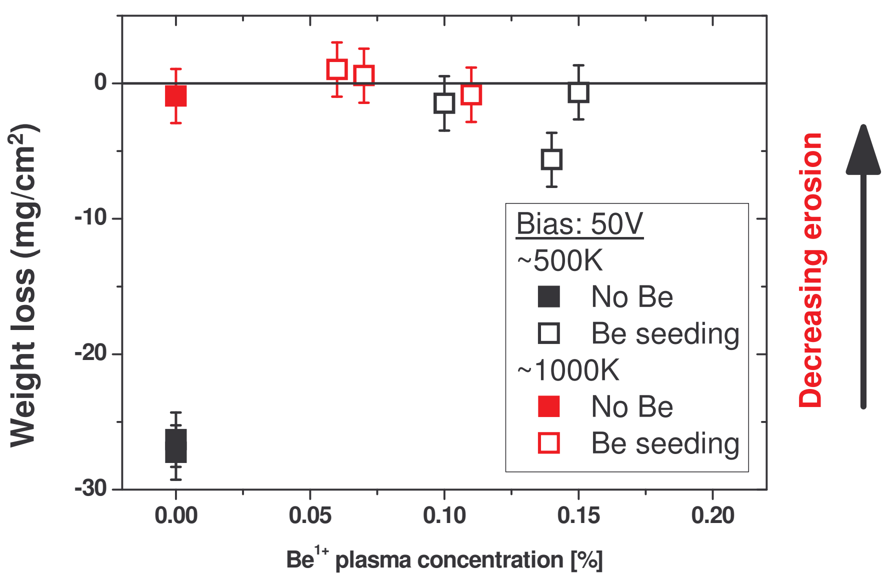
-50 V bias, 200ºC, T_e = 8 eV, n_e = 3 e 12 cm^{-3}



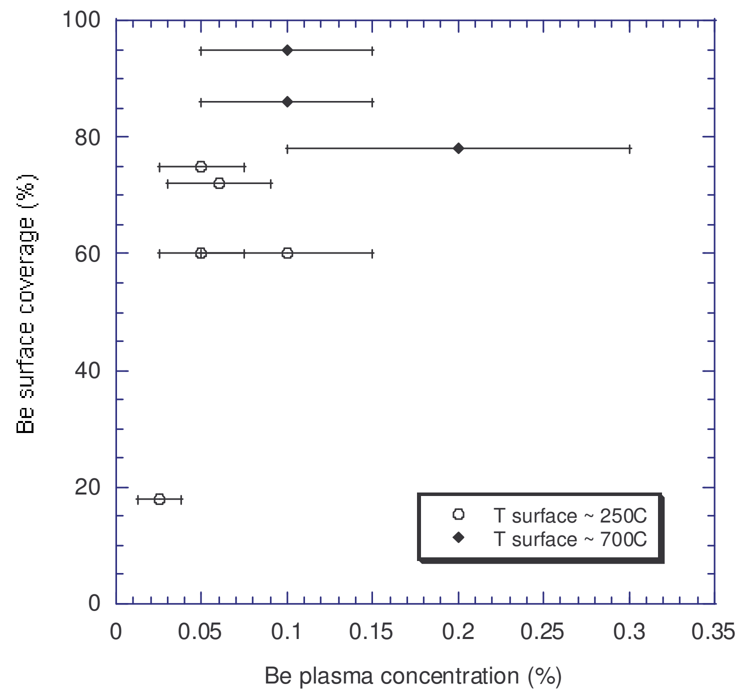


Be rich surface layers form during exposure and shield underlying carbon from erosion

Weight loss data confirms reduction in erosion seen spectroscopically

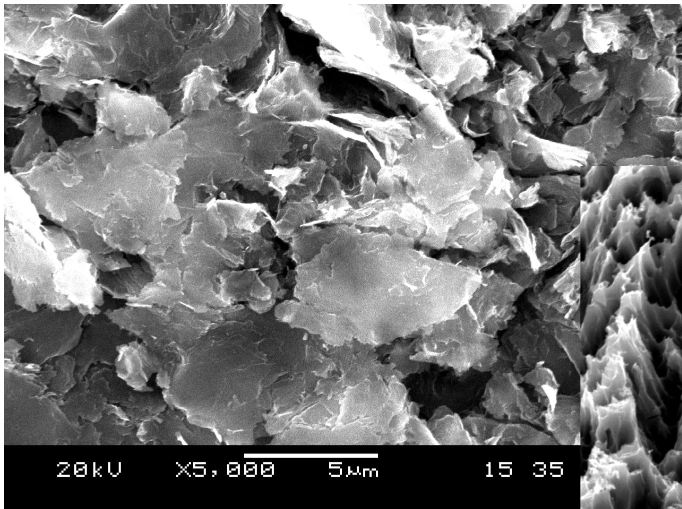


Be surface concentration after 5000 sec. P-B exposure.

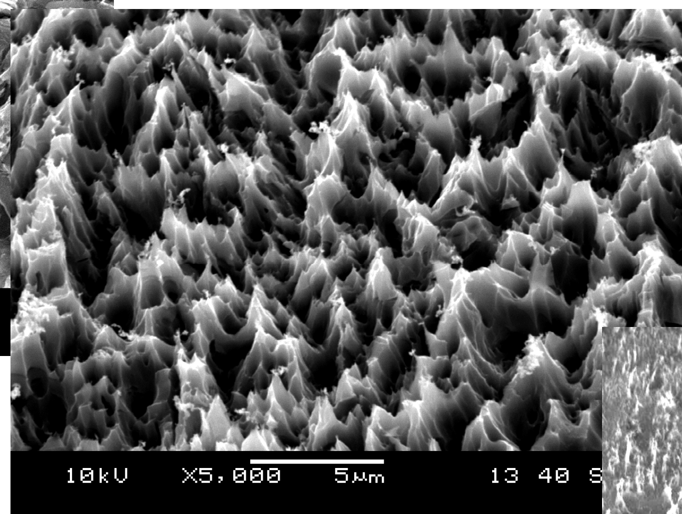


- ITER will have 1-10% Be impurity concentration in the divertor plasma

Be layer forms on C targets with a complicated three dimensional structure

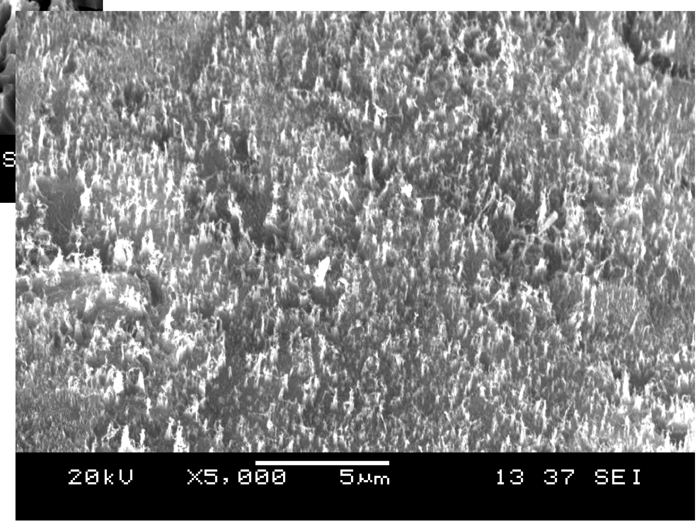


ATJ graphite
Not exposed



No Be seeding
Δm = - 62 mg

~0.1 % *Be seeding*
Δm = - 5 mg
AES - 85 % Be,
10% O & 5% C



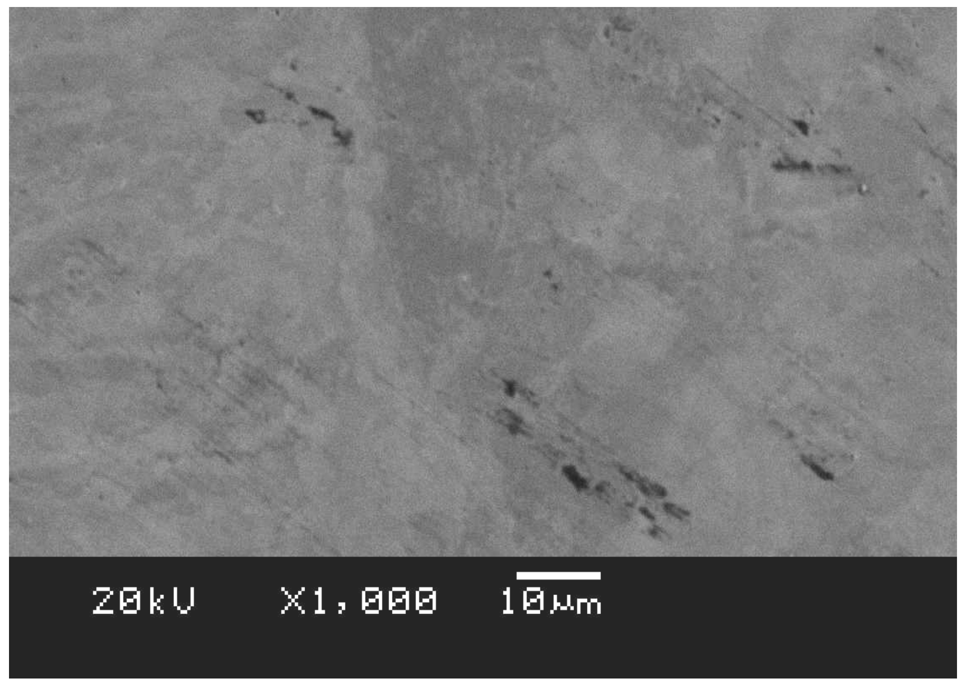
Plasma conditions:

Γ_D ~3x10^{18} cm^{-2} s^{-1}, T_e~ 6eV, n_e~ 10^{12} cm^{-3}, T ~500 K, D Ion Fluence ~2x10^{22} cm^{-2}

Be impurities from the ITER first wall can also form Be-rich surfaces on the tungsten baffle plates

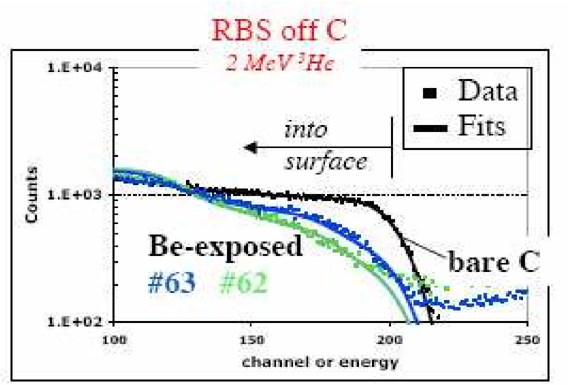
- Be layers have been observed on on W surfaces, as well as C
- Plasma exposure conditions
  - Be conc. ~0.1%
  - E_{ion} ~ 75 eV
  - T_W ~ 300 °C
  - Ion flux ~ 1×10^{22} $m^{-2}s^{-1}$
  - Exposure time = 5000 sec.
- Surface has 12 times as much Be as W indicating formation of $Be_{12}W$ tungsten beryllide alloy (T_{melt} of $Be_{12}W$ ~ 1500 °C)

Surface morphology of a W target exposed to a Be seeded deuterium plasma in PISCES-B

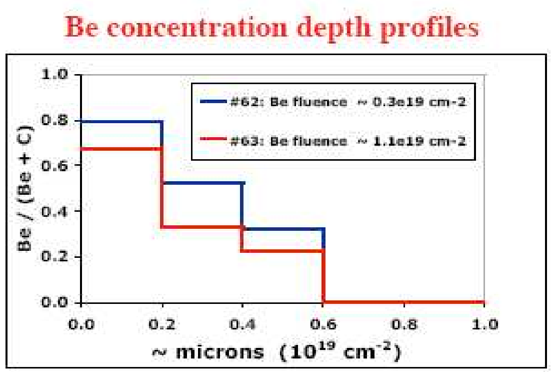


If alloy formation (carbide or beryllide) is responsible for Be layers, then subsequent Be deposition should be quickly re-eroded, which means Be alloy layers should be thin.

C sample, 175°C, f_{Be} ~0.15%



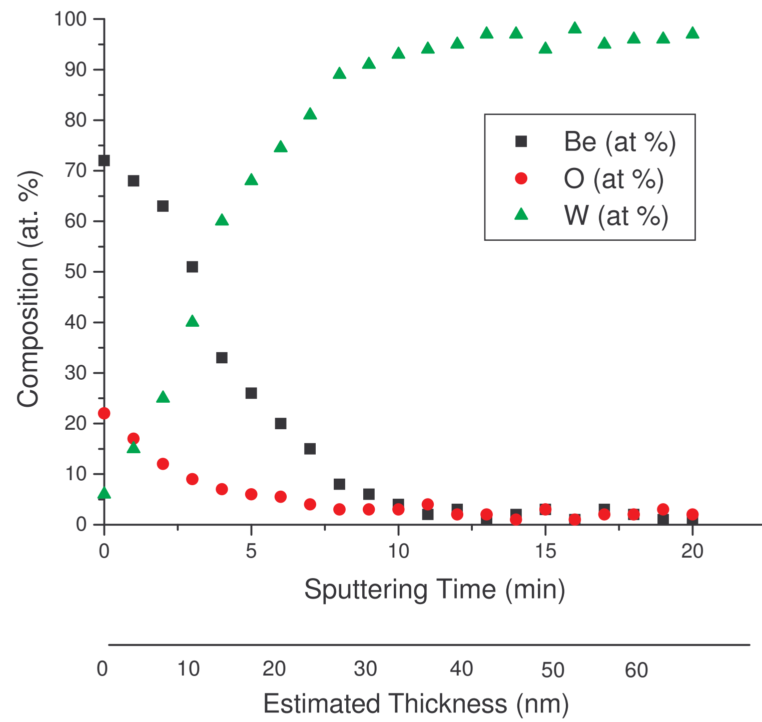
- RBS shows that the carbon is depleted in the near surface and replaced by Be.



- Fits show that the Be enrichment is not constant, but decreases deeper into the sample.

W sample (AES data)

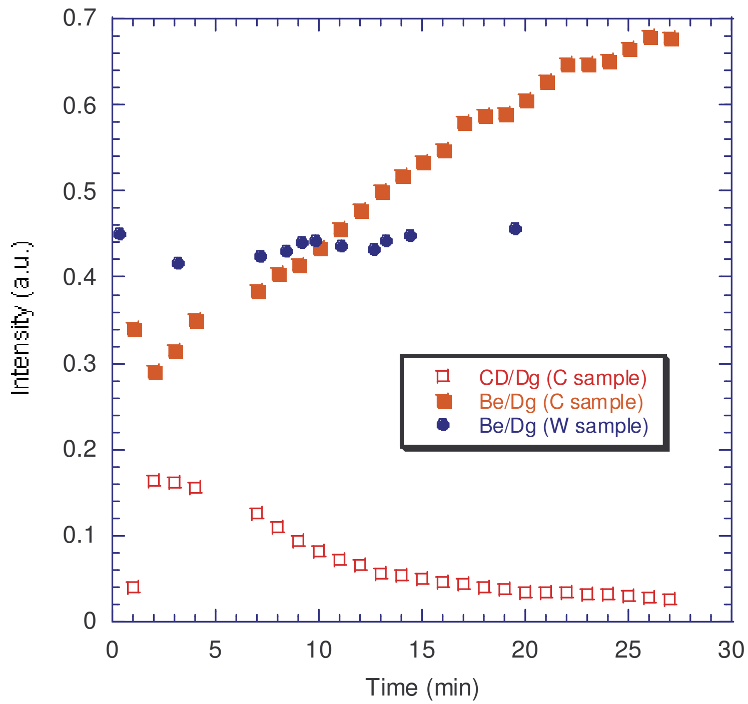
f_{Be} = 0.1%, 5000 sec., T_W = 300°C



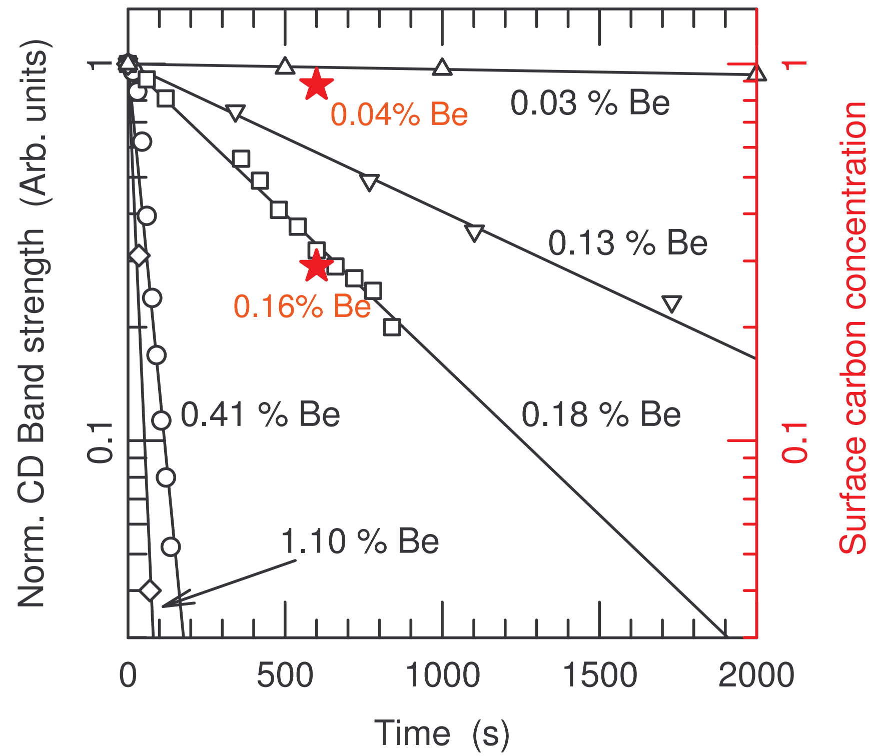
The dynamic behavior of the Be layer may help decipher the mechanisms responsible for surface layer formation on C and W substrates

- PISCES-B conditions: f_{Be} ~ 0.001, Γ_{pl} = 3e18 $cm^{-2}s^{-1}$, Γ_{Be} = 3e15 Be/cm^2s or 1 Be monolayer/sec

Be layers appear to form rapidly on W samples under PISCES-B plasma conditions



Be layers can form slowly on C samples under PISCES-B conditions



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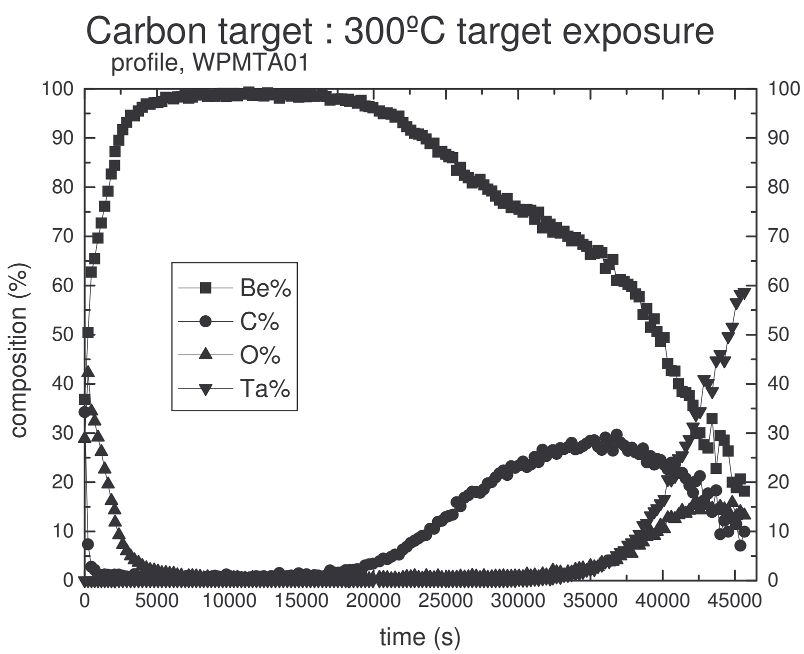
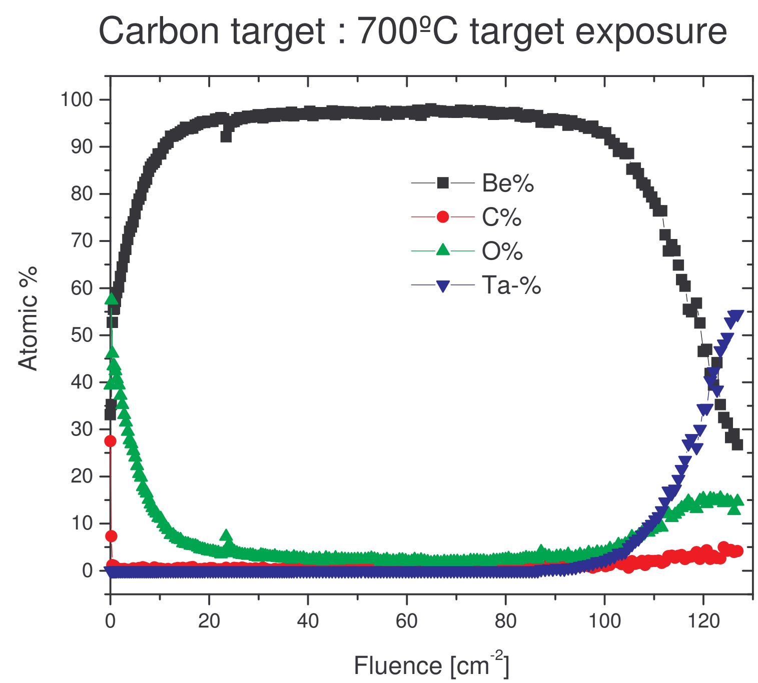
Erosion mechanism will determine fuel retention. Fuel accumulation within ITER is a critical operational and safety issue

- PISCES witness plate manipulator (WPM) allows investigation of codeposited material eroded from targets
- PISCES target analysis examines implantation and saturation issues associated with high-flux plasma interaction locations
- NRA (at IPP and UW-Madison) and TDS (at UCSD) allow quantitative comparison of retention measurements

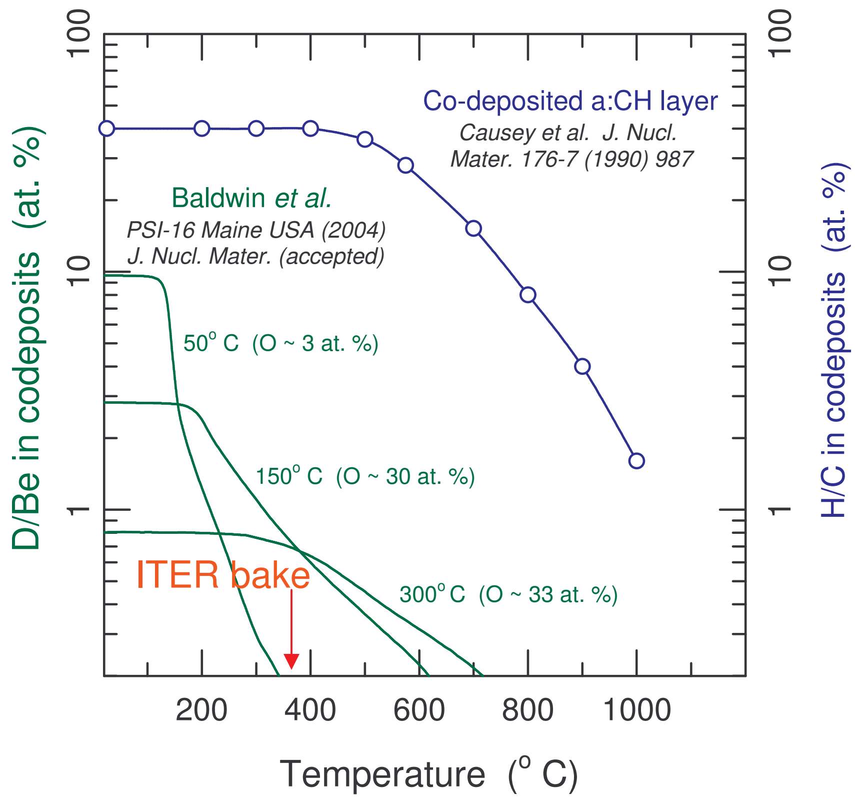
WPM samples show collection of beryllium rich deposits during Be seeding runs





No WPM data yet from W targets,
but large loss rate of incident Be ions on W targets (re-erosion or reflection) quickly causes coating of diagnostic windows during Be seeding runs

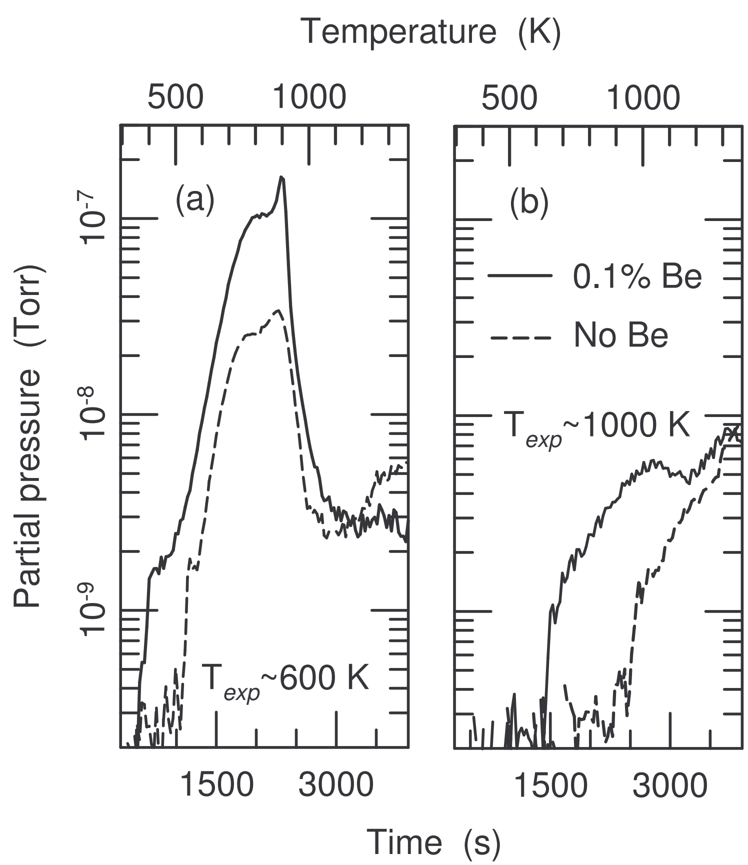
T retained in Be rich codeposits can be more easily removed during divertor bakeout



- Although more hydrogen isotopes are retained during lower temperature codeposition, they are more easily desorbed
- ITER can bake divertor to 375℃ (after coolant drain)
- Codeposits will be in line-of-sight of erosion location
- Oxygen bake may not be needed to remove fuel atoms from codeposits

Hydrogen isotopes are not so easily removed from locations of direct plasma contact

TDS of C targets w/ & w/o Be seeding



- Data from erosion dominated regimes in PISCES
- More fuel atoms are retained in targets during Be seeding runs
- Presence of Be has little influence on desorption characteristics of C targets
- Flash heating of strikepoints (i.e. laser, flashlamp or controlled plasma power deposition) could be used if target retention becomes an issue for ITER

US-EU Collaboration on Be/C/W has produced significant new results, but more work is needed.

- Understand mechanism responsible for Be-rich layer formation at very low impurity Be concentration (~0.1%)
- Develop/benchmark models that can predict the dynamic behavior of the Be coating process
- Subject layers to ELM style heat pulses during formation
- Investigate similarities and differences of W & C targets
- Investigate concurrent Be and C injection into D plasma
- Investigate role of other impurities (i.e. oxygen, carbon, radiating noble gases)
- W-Be alloy formation is a critical issue needing immediate attention (melting temperature, thermal properties, formation rates, tritium retention, etc.)
  See talk by M. Baldwin

Be impurities may dominate PMI (specifically tritium accumulation) in devices with large area Be walls

- Need to accurately predict first wall erosion rates (CX, diffusion, convective transport)
- Understanding SOL flows in confinement devices is crucial to predicting divertor impurity content
- Need benchmarked PMI models to predict behavior of surfaces with some confidence